The next Heavy Ion Jet INteraction Generator HIJING++

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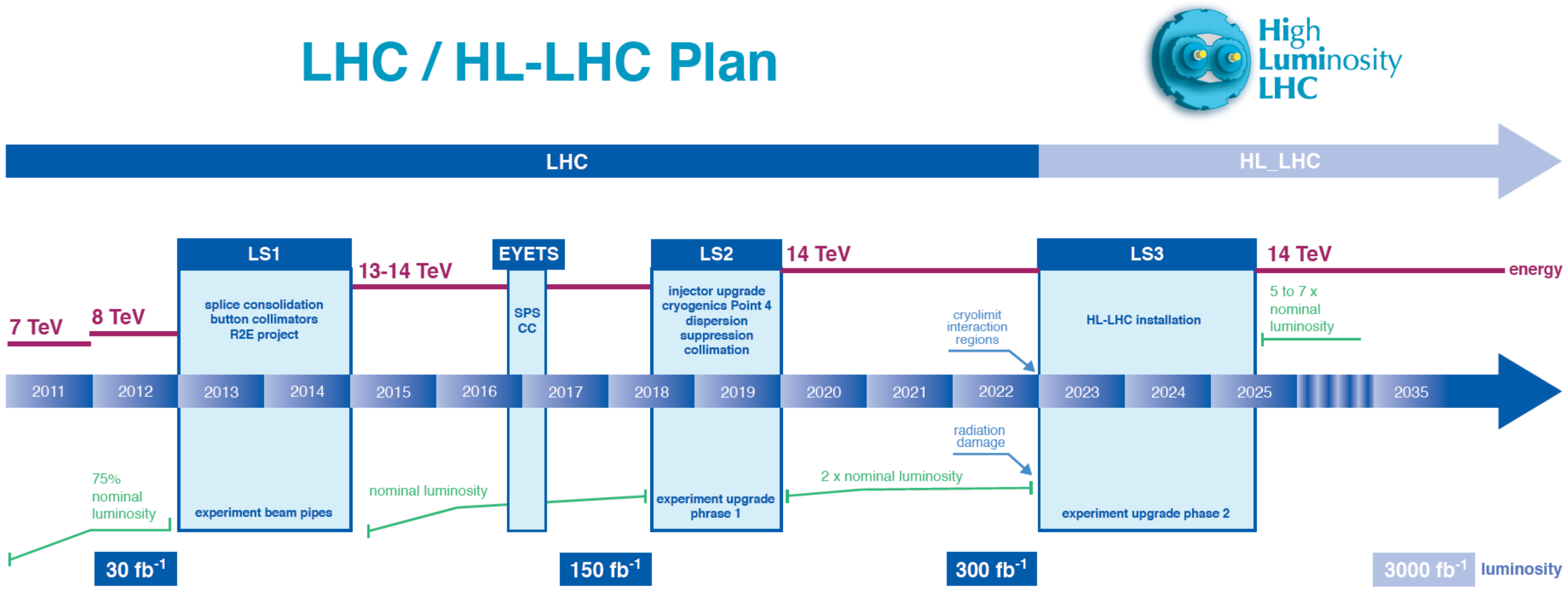
Motivation

- Need for more data, higher statistics….



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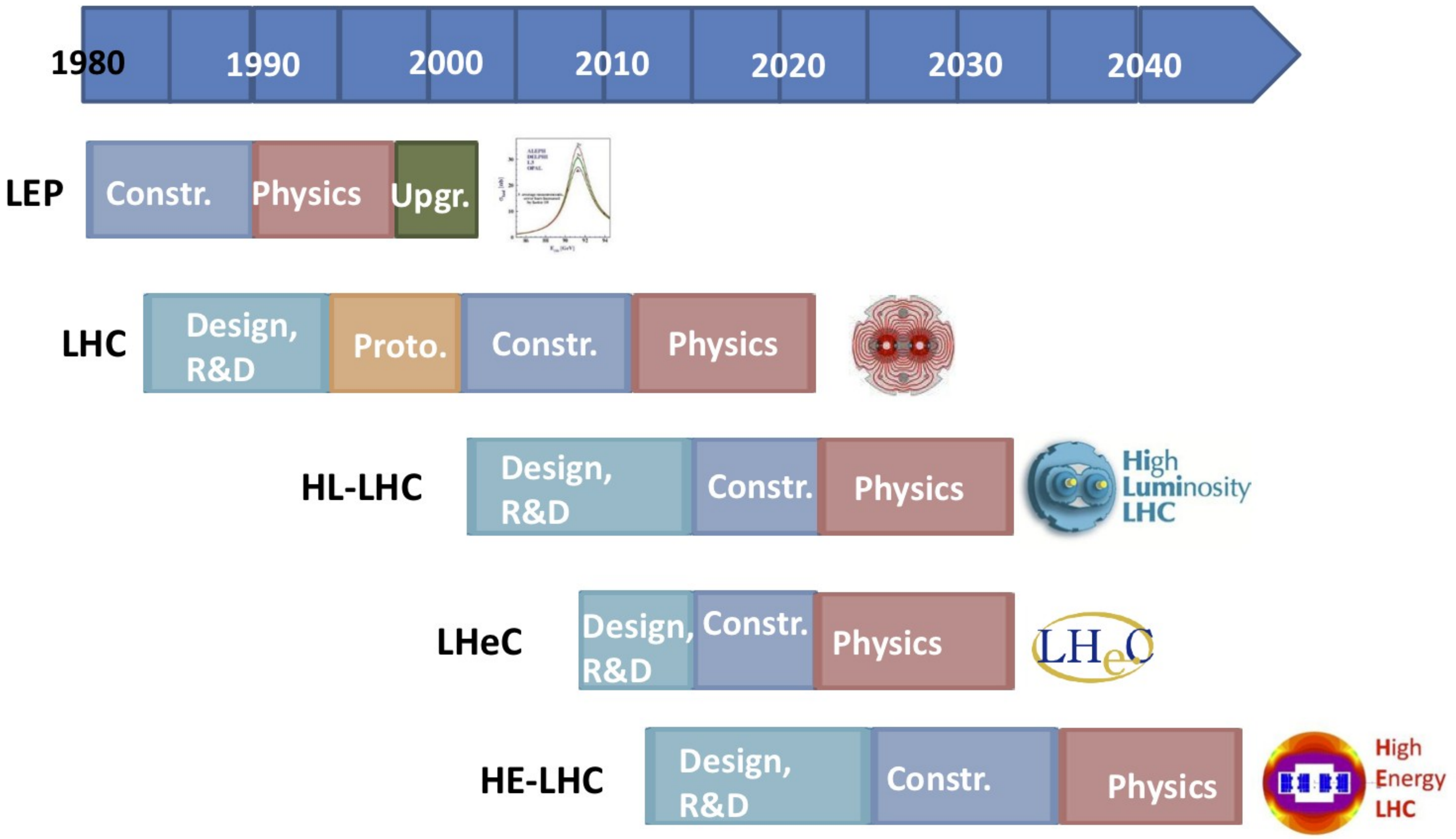

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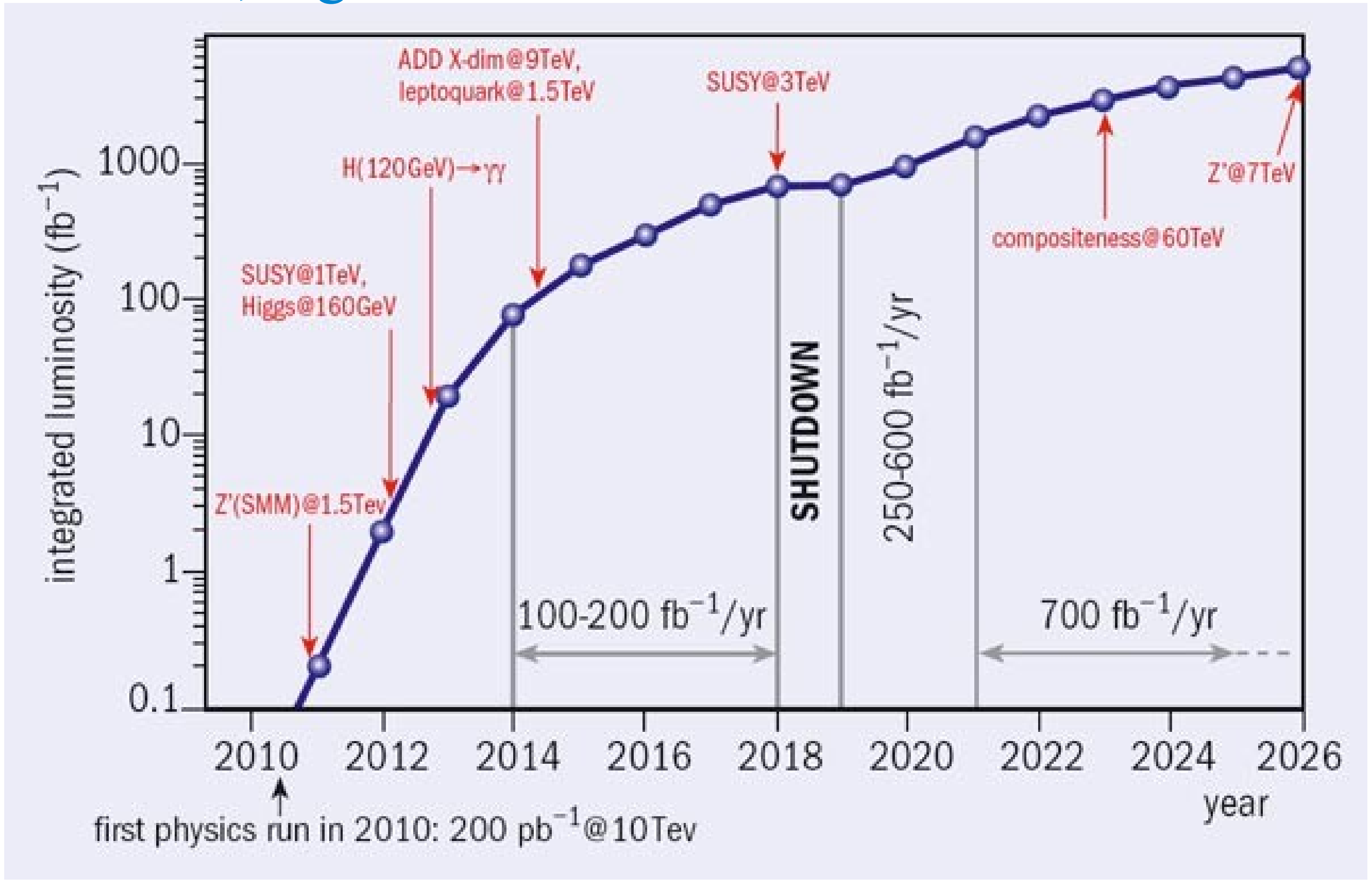
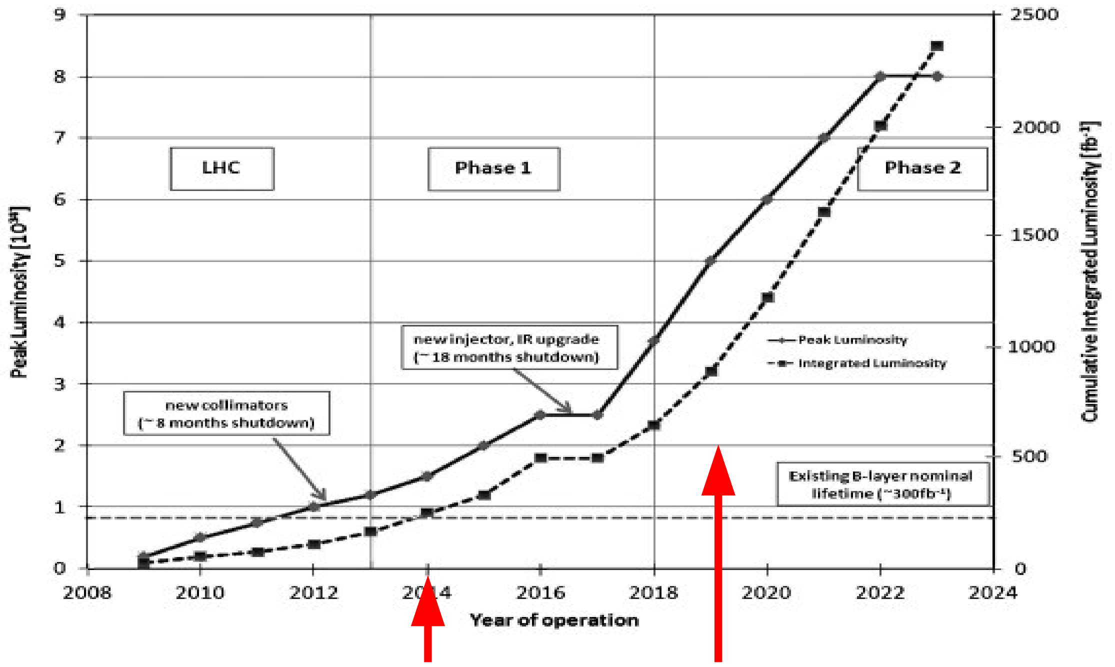
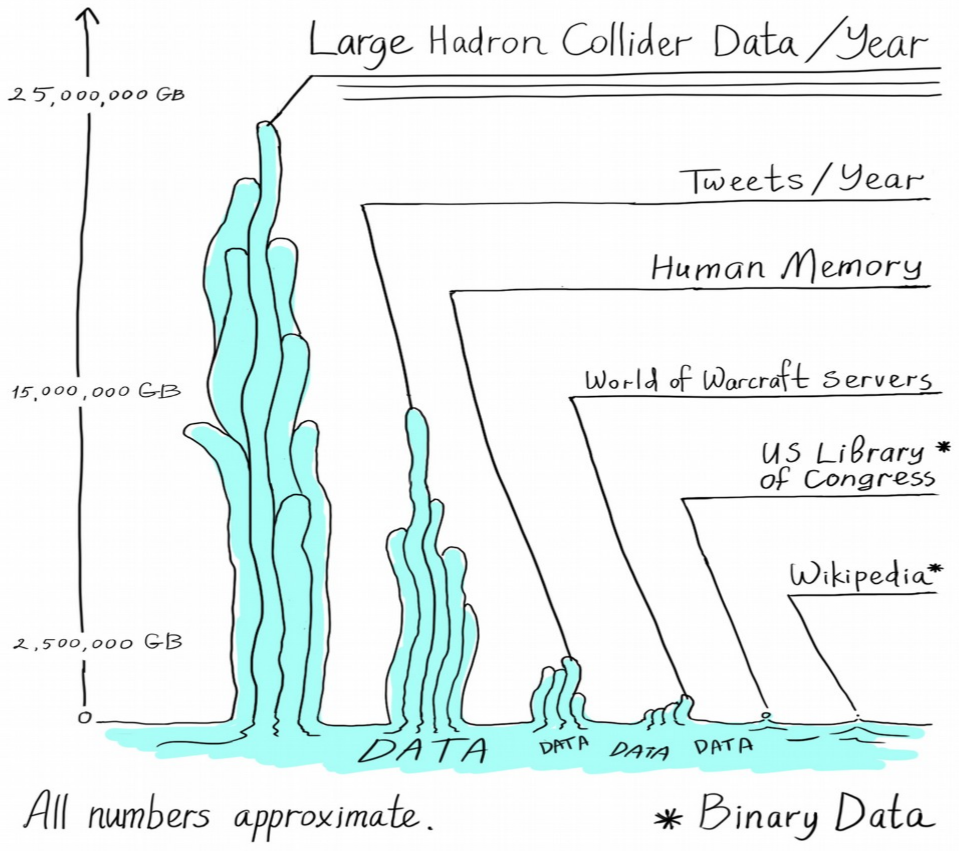


Motivation

- WLCG – Worldwide LHC Computing GRID:
  - 15-20 Petabytes data per year
  - ...and more after LHC upgrades

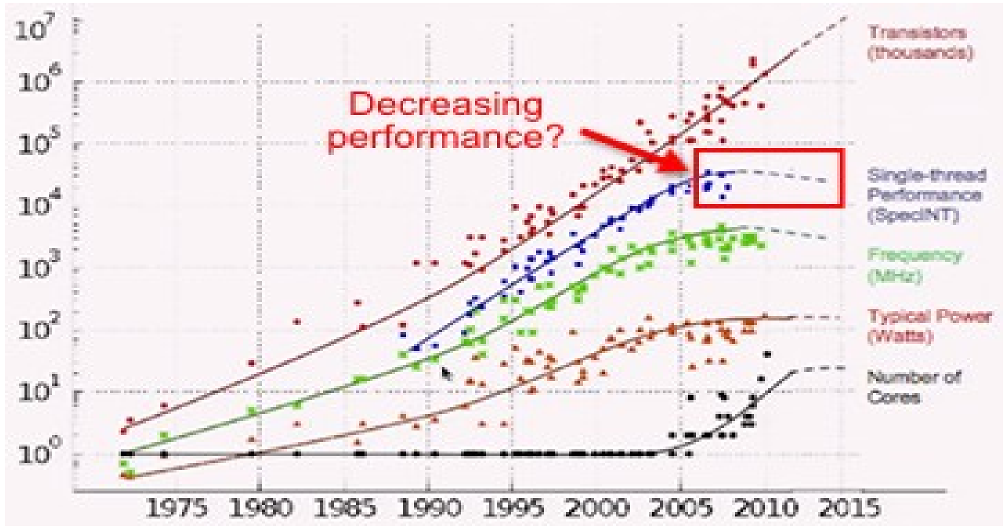




Fast computing

- Moore's law:

Every 2nd year the number of transistors (integrated circuits) are doubled in computing hardwares.



Fast computing = parallel computing

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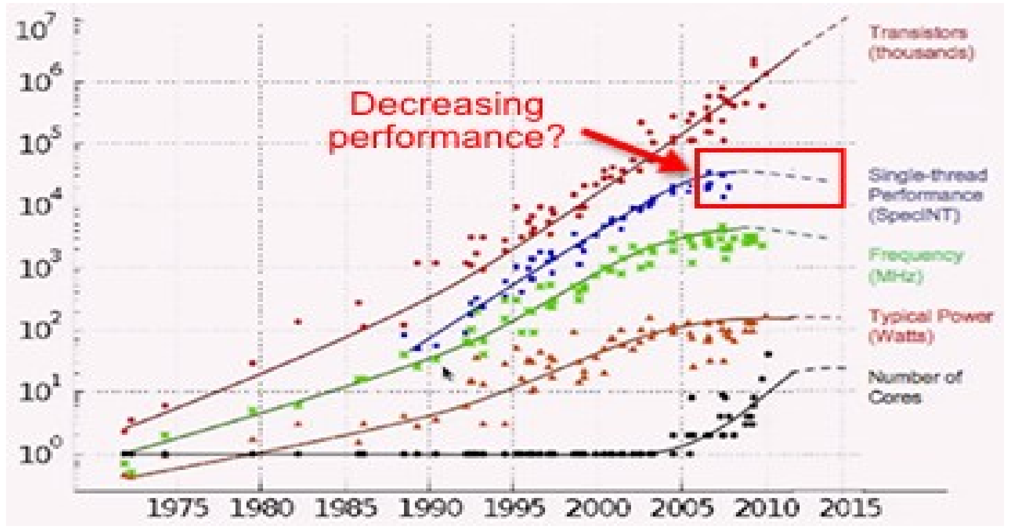
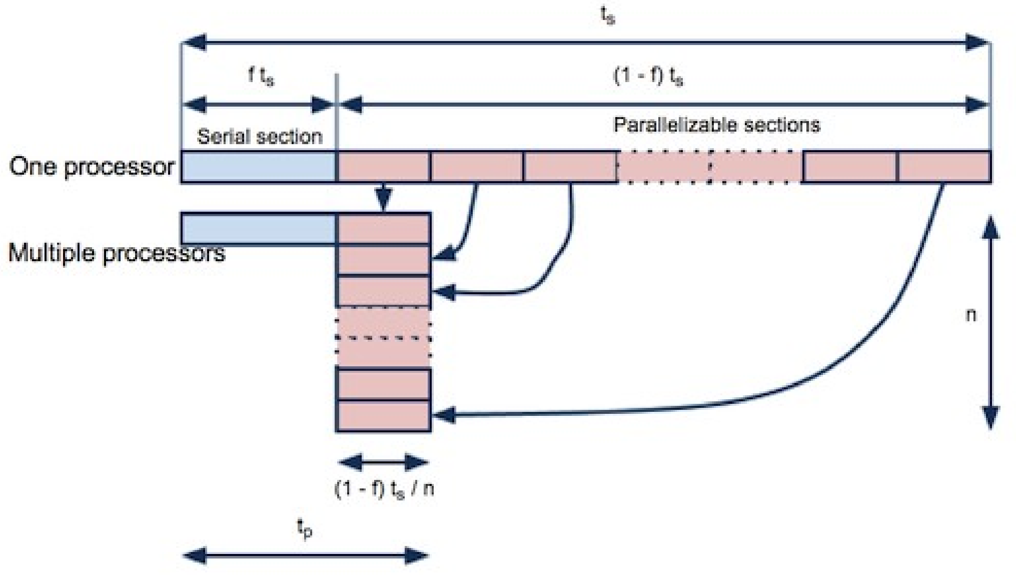


- Amdalh's law:

The theoretical speedup is given by the portion of parallelizable program, p, & number of processors (threads), N, is:



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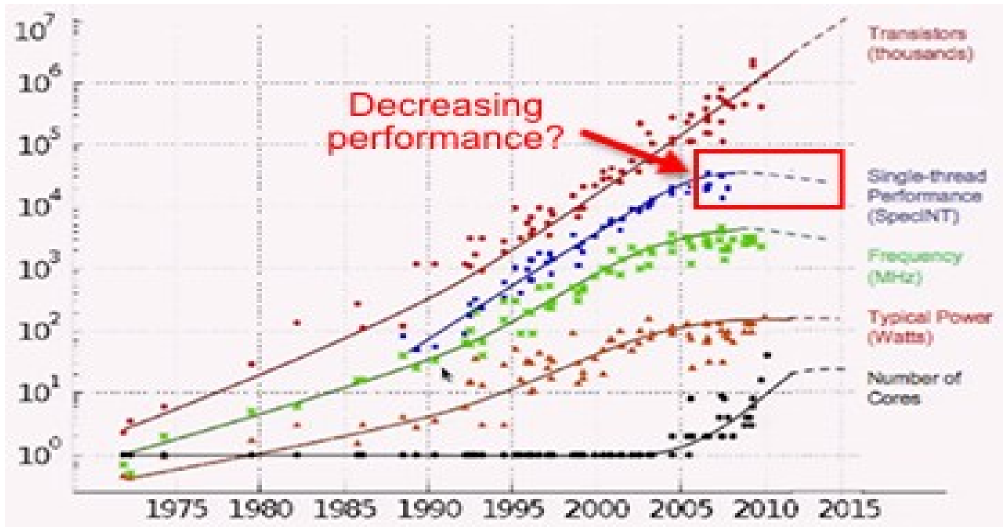


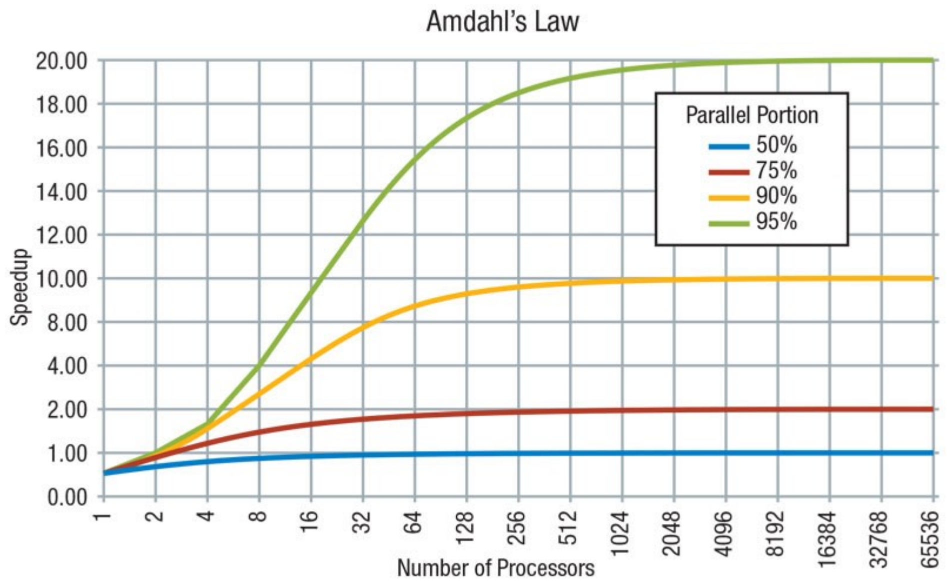
- Amdalh's law:

The theoretical speedup is given by the portion of parallelizable program, p, & number of processors (threads), N, is:

$$\text{Speedup}(N) = \frac{1}{(1-P)+\frac{P}{N}}$$

Serial part of job = 1 (100%) - Parallel part

Parallel part is divided up by N workers



Introduction to HIJING++

- HIJING(Heavy-Ion Jet INteraction Generator)

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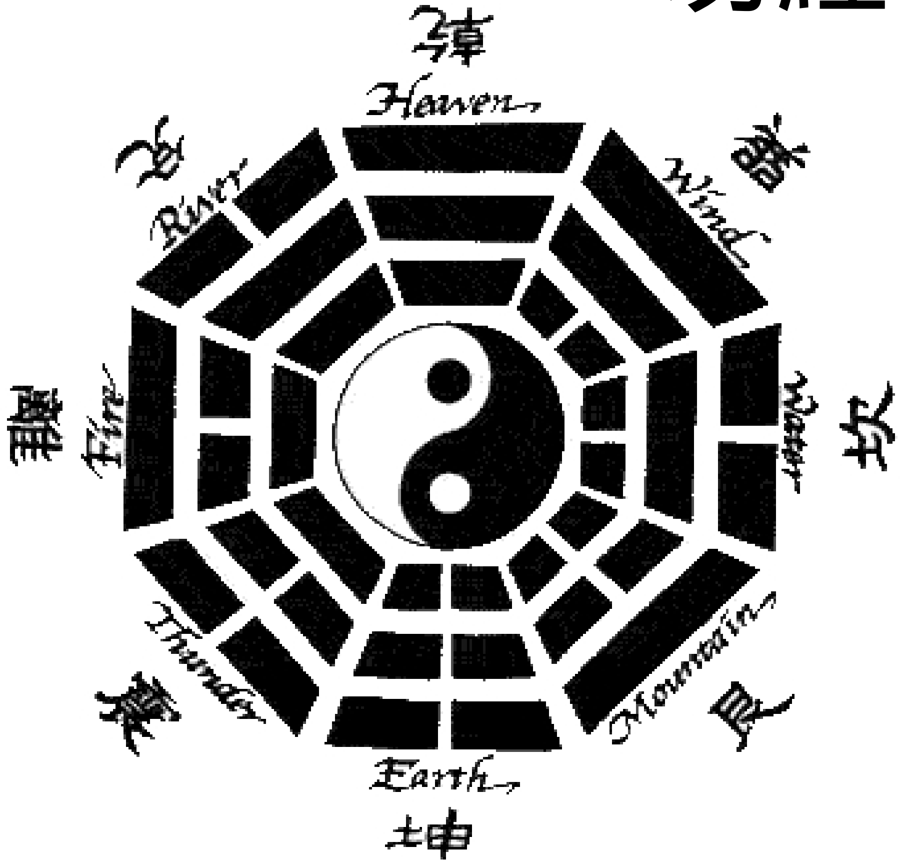


Bagua (eight simbols)

fundamental principles of reality

adjoint representation 8 of *SU(3)*

Historical Review

- HIJING(Heavy-Ion Jet INteraction Generator)

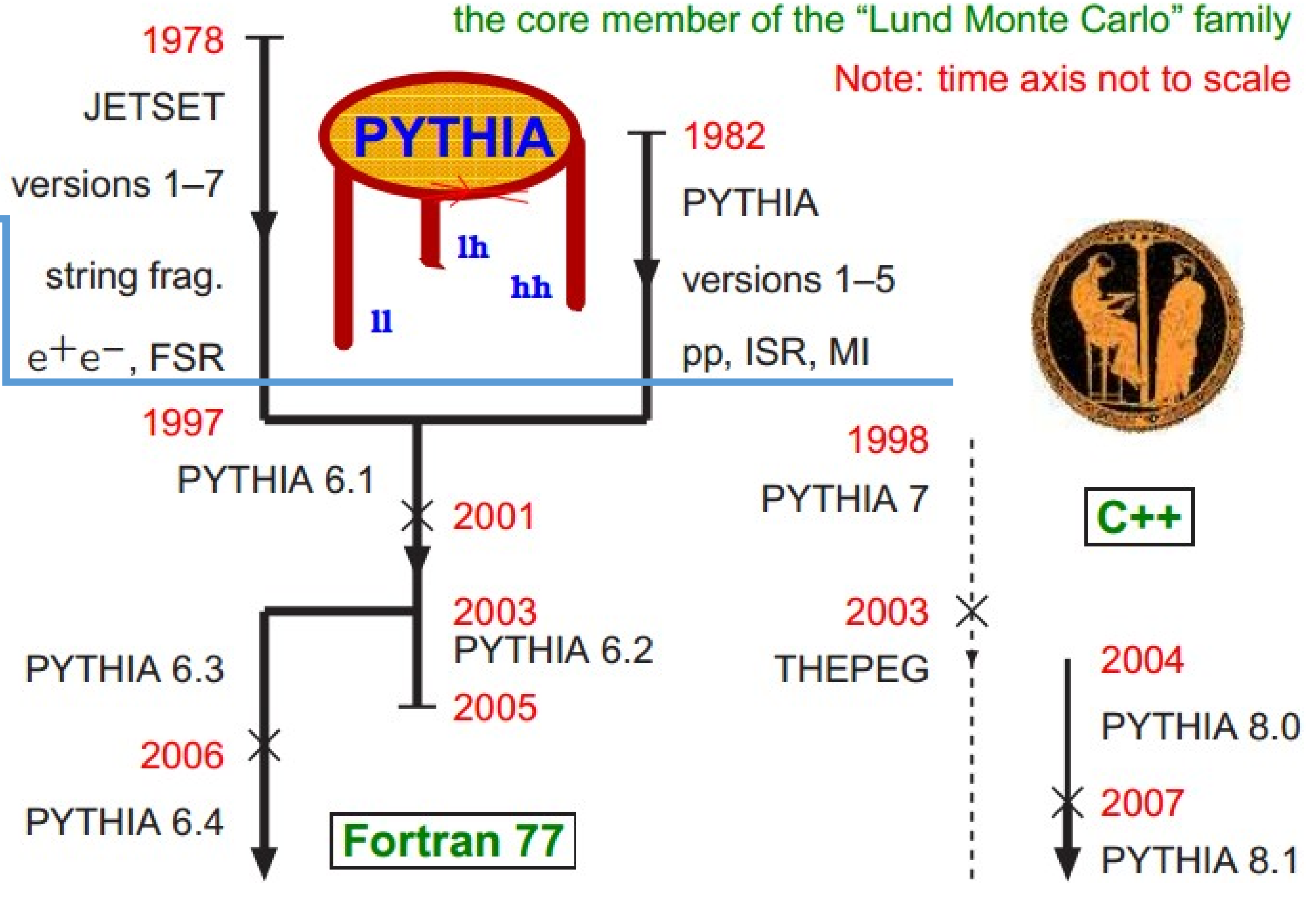
- HIJING versions
  - FORTRAN v1.36, v2.553
  - C++ v3.0

Reasons to use C++

Object oriented language: Hierarchy, Modularity

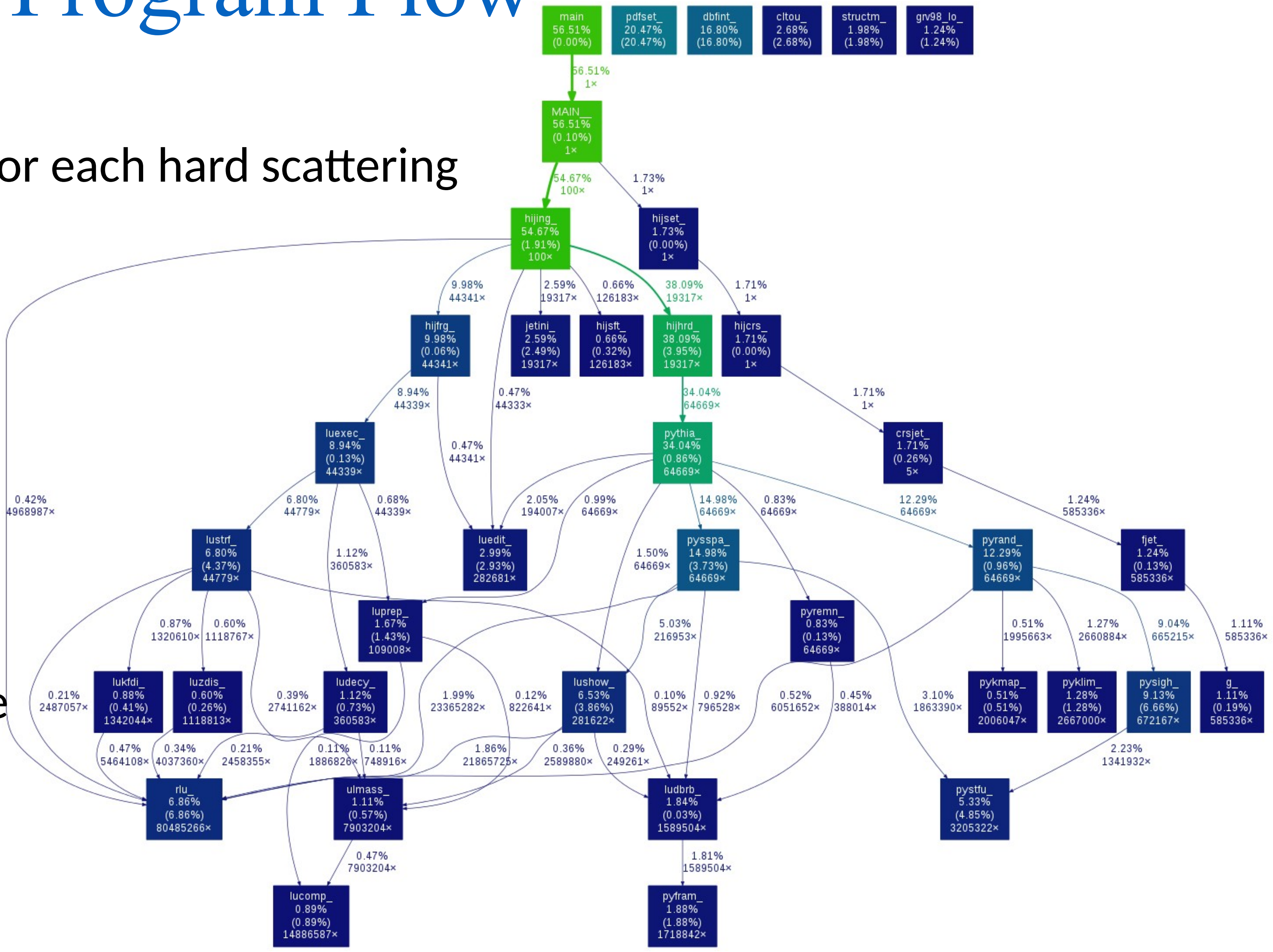
C++11/14 has thread support
and compatibility with OpenCL

PYTHIA history



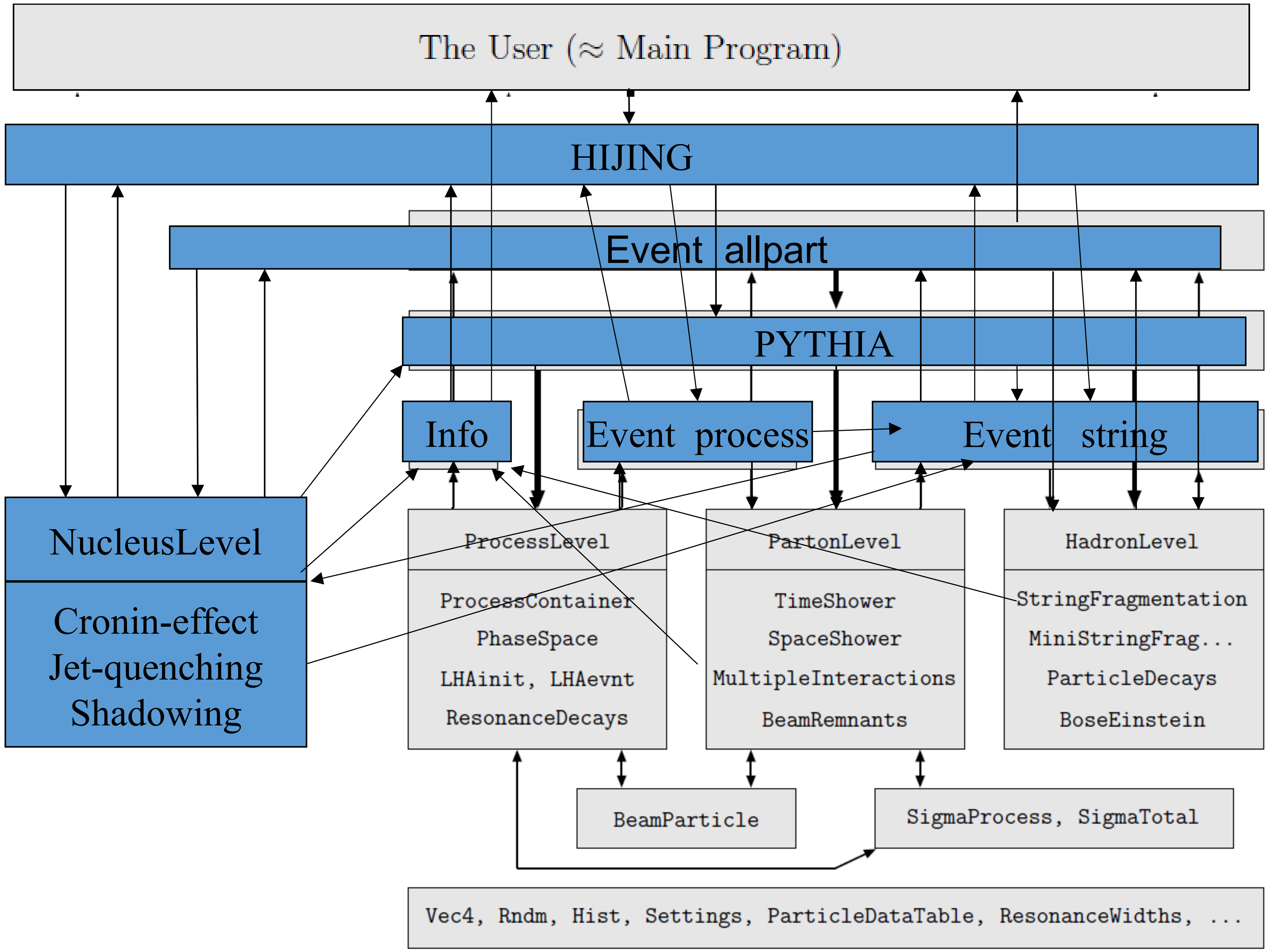
Program Flow

- Generation of kinetic variables for each hard scattering with Pythia 5.3
- Multiple soft gluon exchanges between valence- and diquarks
- String hadronization according to Lund fragmentation scheme


main_ 56.51% (0.00%)
pdfset_ 20.47% (20.47%)
dbfint_ 16.80% (16.80%)
cltou_ 2.68% (2.68%)
structm_ 1.98% (1.98%)
grv98_lo_ 1.24% (1.24%)
MAIN__ 56.51% (0.10%) 1×
hijing_ 54.67% (1.91%) 100×
hijset_ 1.73% (0.00%) 1×
hijfrg_ 9.98% (0.06%) 44341×
jetini_ 2.59% (2.49%) 19317×
hijsft_ 0.66% (0.32%) 126183×
hijhrd_ 38.09% (3.95%) 19317×
hijcrs_ 1.71% (0.00%) 1×
luexec_ 8.94% (0.13%) 44339×
pythia_ 34.04% (0.86%) 64669×
crsjet_ 1.71% (0.26%) 5×
lustrf_ 6.80% (4.37%) 44779×
luedit_ 2.99% (2.93%) 282681×
pysspa_ 14.98% (3.73%) 64669×
pyrand_ 12.29% (0.96%) 64669×
fjet_ 1.24% (0.13%) 585336×
luprep_ 1.67% (1.43%) 109008×
pyremn_ 0.83% (0.13%) 64669×
lukfdi_ 0.88% (0.41%) 1342044×
luzdis_ 0.60% (0.26%) 1118813×
ludecy_ 1.12% (0.73%) 360583×
lushow_ 6.53% (3.86%) 281622×
pykmap_ 0.51% (0.51%) 2006047×
pyklim_ 1.28% (1.28%) 2667000×
pysigh_ 9.13% (6.66%) 672167×
g_ 1.11% (0.19%) 585336×
rlu_ 6.86% (6.86%) 80485266×
ulmass_ 1.11% (0.57%) 7903204×
ludbrb_ 1.84% (0.03%) 1589504×
pystfu_ 5.33% (4.85%) 3205322×
lucomp_ 0.89% (0.89%) 14886587×
pyfram_ 1.88% (1.88%) 1718842×

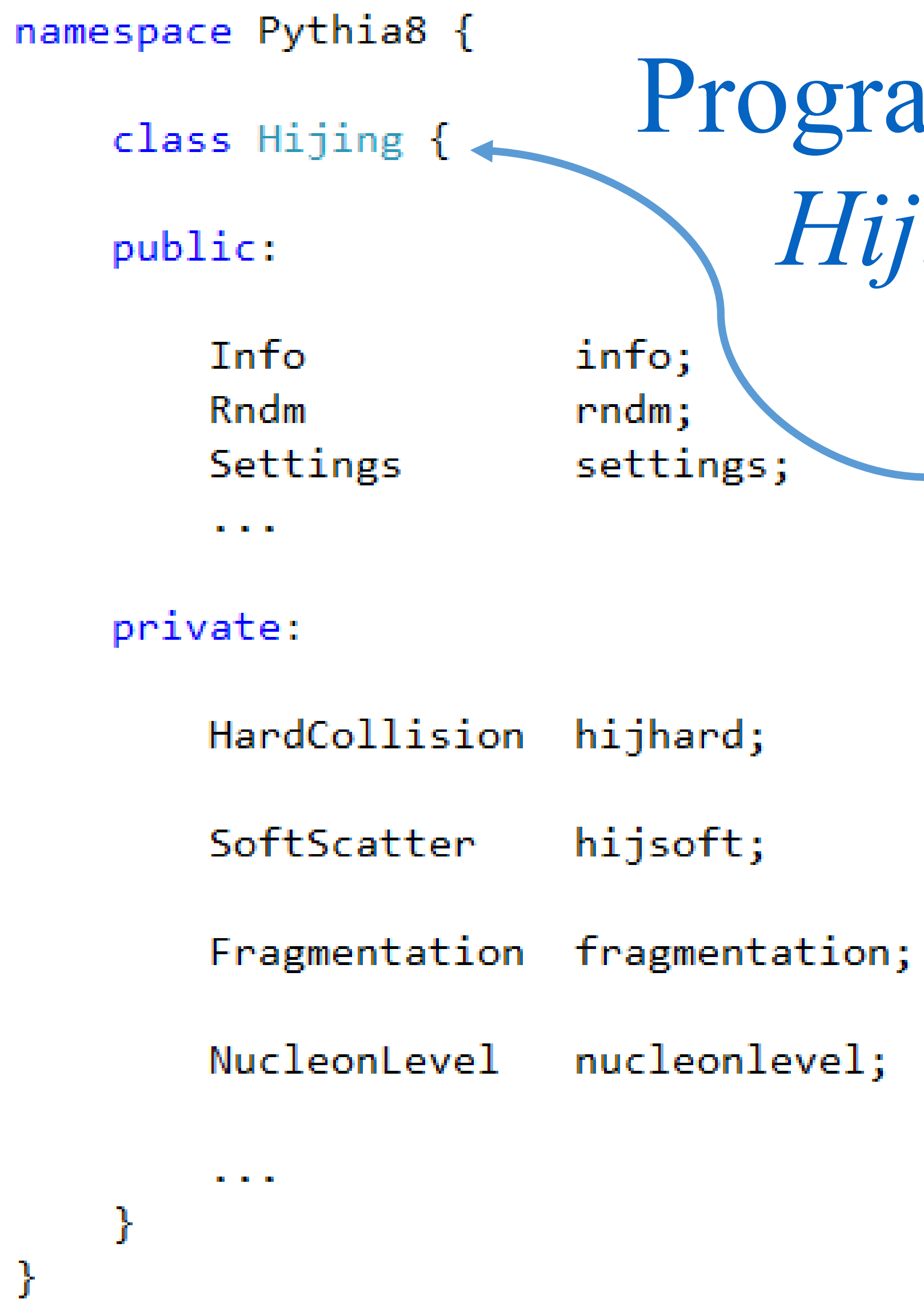
Program Structure

- Pythia8 namespace containers
- Structure similarities
- Actual program flow is more complicated



Program Structure

Hijing class



```
namespace Pythia8 {

    class Hijing {

    public:

        Info            info;
        Rndm            rndm;
        Settings        settings;
        ...

    private:

        HardCollision   hijhard;

        SoftScatter     hijsoft;

        Fragmentation   fragmentation;

        NucleonLevel    nucleonlevel;


        ...
    }
}
```

- Processes ordered in class hierarchy
- Former common blocks → class variables
- Processes called through object functions

// Class for handling the hard collisions

// Class for handling the soft interactions

// Class for handling the Lund string fragmentation

// Class for the nuclear effects

Main example

Usual form kept for regular users

FORTRAN

```
PROGRAM TEST
...
PARM(1) = 'DEFAULT'
VALUE(1) = 80060
CALL PDFSET(PARM, VALUE)
CALL GetDesc()
...

CALL HIJSET(EFRM, FRAME, PROJ, TARG, IAP, IZP, IAT, IZT)

N_EVENT=1E6
DO 200 IE = 1, N_EVENT
    CALL HIJING(FRAME, BMIN, BMAX)
200 CONTINUE

STOP
END
```

Form also similar to Pythia 8.x

C++

```
#include "Hijing.h"

using namespace Pythia8;

int main() {
    Hijing hijing("../xmldoc", true);
    hijing.readString("PDF:pSet = LHAPDF6:GRV98lo");

    bool okay = hijing.init(200.0, frame,
                  "A", "A", 197, 79, 197, 79);
    if (!okay) return 1;

    int MaxEvent = 1e6;
    for (int iEvent = 0; iEvent < MaxEvent; ++iEvent)
        hijing.next(frame, 0.0, 0.0);
}
```

Program Features

- Calculation by improved models
- Pythia like prompt Histogram creation
- CPU level Parallel computing

```
const std::size_t num_threads = std::thread::hardware_concurrency();
for (std::size_t i = 0u; i < num_threads; ++i){
    async_hijing.at(i) = std::unique_ptr<Hijing>(new Hijing);
}
for (std::size_t I = 0; I < num_threads; ++I){
    ...async run...
    okay[I] = async_hijing[I]->init(...);
    for (int iEvent = 0; iEvent < numEvent; ++iEvent)
        async_hijing[I]->next(...);
    for (int i = 0; i < async_hijing[I]->event.size(); ++i)
        if(...) hist[I]->fill(...);
}
```

THE C++ STANDARD TEMPLATE LIBRARY

- AliRoot compatibility (planned)

Model Improvements

- Shadowing

  HIJING 2.0 fits RHIC data well
  Improvements are needed for LHC energy

  $$R_i(x,b) \;\rightarrow\; R_i(Q,x,b)$$

- Jet-Quenching

  Various models: accuracy ⊒ ⊓ speed

- Soft QCD radiation

  updated ARIADNE calls

- (already implemented improvements since v1.36)

Dependencies & External packages

- Boost

```
sudo apt-get install libboost-all-dev
```

- LHAPDF 6

```
./configure –prefix=$HOME/…/share/LHAPDF
make all
```

insert downloaded PDF library to $HOME/…/share/LHAPDF

optionally modify **pdfsets.index**, add set if needed

```
export LD LIBRARY PATH=<library path>
```

- Pythia 8

```
./configure --with-lhapdf6-lib=$HOME/…/lib \
--with-boost-lib=/usr/lib/x86_64-linux-gnu
make –j4
```

- GSL (optional)

HIJING **make** option

Data Analysis

```
#include "Hijing.h"
using namespace Pythia8;

int main() {
    Hist dndpT("dn/dpT for charged particles", 100, 0., 10.);
    ofstream ch_file("ch_hist.dat");
    ...
    bool okay = hijing.init(efrm, frame, proj, targ,
                            aproj, zproj, atarg, ztarg);
    if (!okay) return 1;
    int MaxEvent = 1e6;
    for (int iEvent = 0; iEvent < MaxEvent; ++iEvent) {
        hijing.next(frame, bmin, bmax);
    for (int i = 0; i < hijing.event.size(); ++i)
    if (hijing.event[i].isFinal() && hijing.event[i].isCharged())
        dndpT.fill(hijing.event[i].pT());
    }
    dndpT *= 1.0 / MaxEvent;
    cout << dndpT;
    dndpT.table(ch_file);
    ...
    return 0;
}
```

Pythia 8 Histogram class available

Selection has to be made for every particle

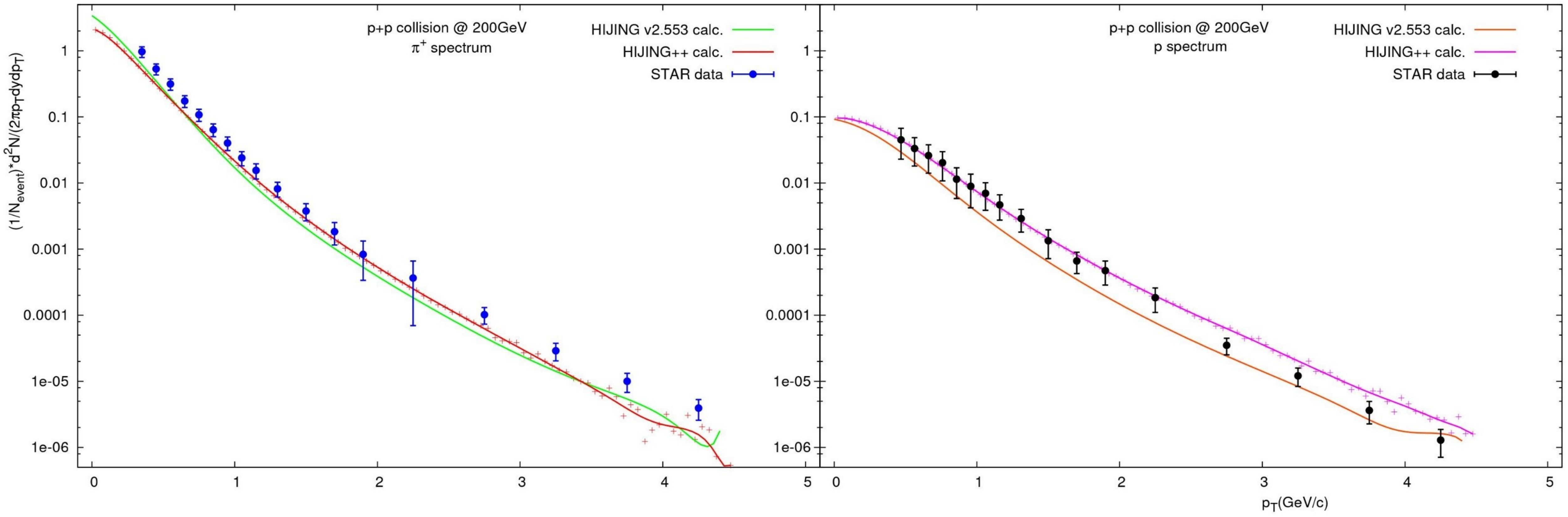
Hist::fill(double Input);

Normalization

standard output and file output both provided

Apetizer plots for the RHIC era

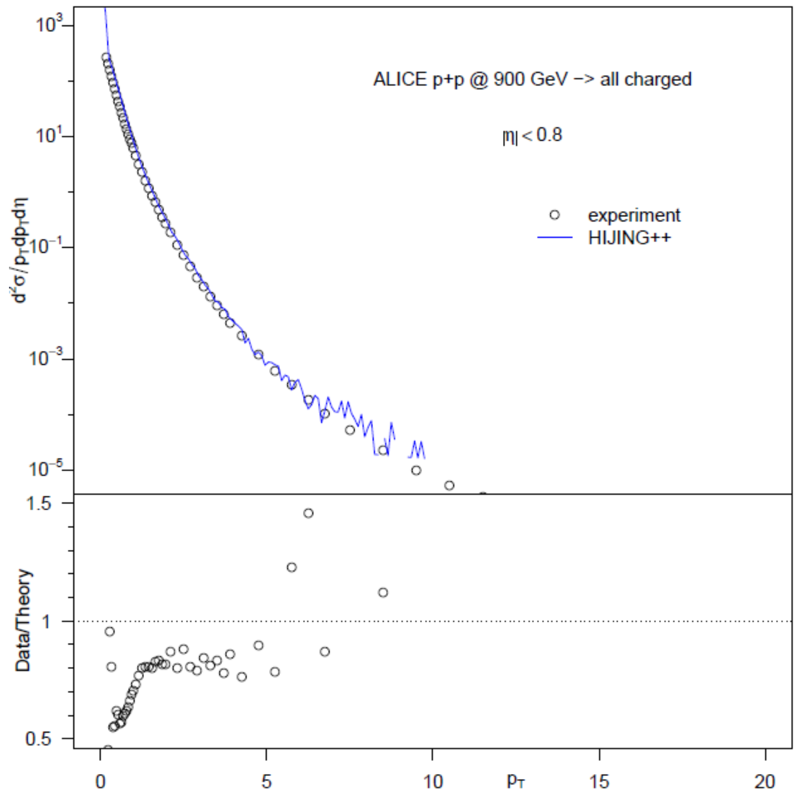
Code validation with „old” version and RHIC data

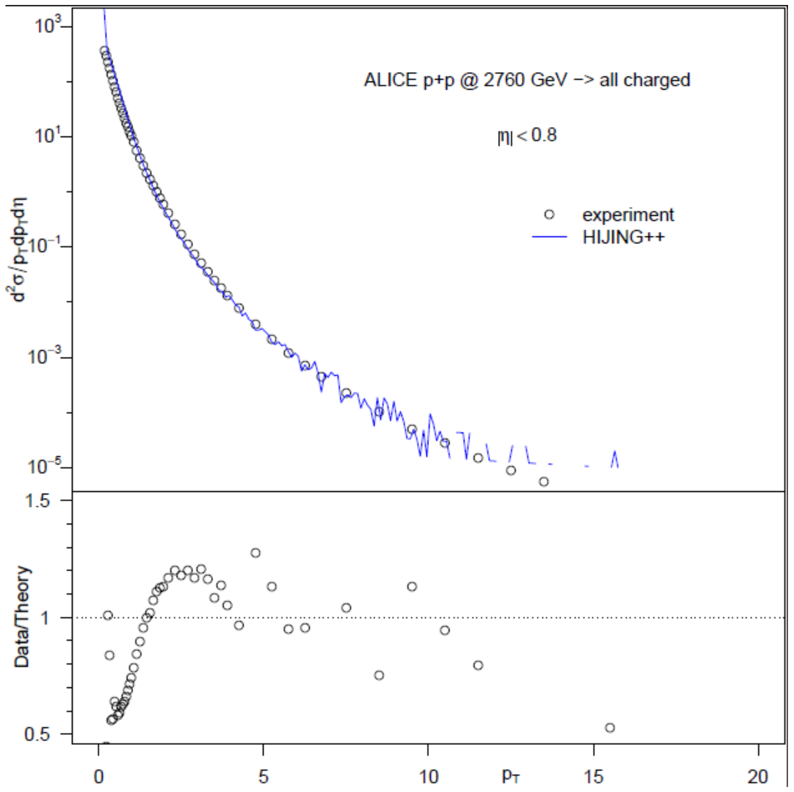


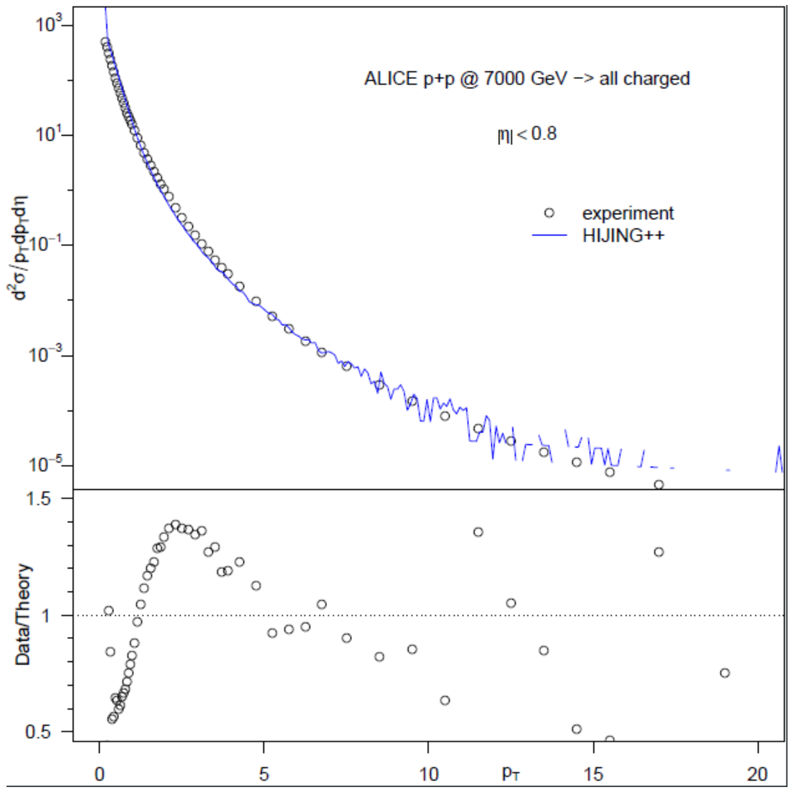
STAR Collaboration, Phys.Lett. B637 page 161-169 (2006)

Apetizer plots for the LHC era

Code validation with LHC pp data at 900, 2760, 7000 GeV c.m. energies.







ALICE Collaboration, 10^9 event

Runtime comparison

For 1e5 Events.

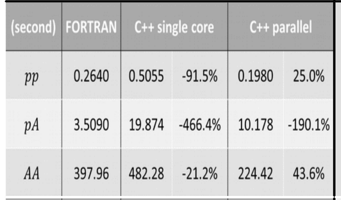
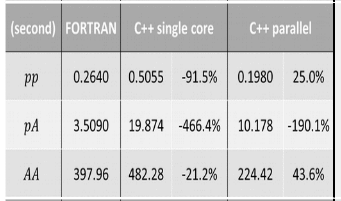
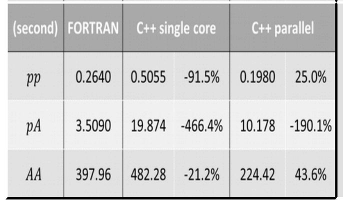
```fortran
integer::beg, end, rate
call system_clock(beg,rate)

(end - beg)/real(rate)
```

```cpp
#include <chrono>

auto start = std::chrono::high_resolution_clock::now();

double runtime = std::chrono::duration_cast<std::chrono::milliseconds>
(end.time_since_epoch() - start.time_since_epoch()).count();
```

(second)	FORTRAN	C++ single core		C++ parallel	
	0.2640	0.5055	-91.5%	0.1980	25.0%
	3.5090	19.874	-466.4%	10.178	-190.1%
	397.96	482.28	-21.2%	224.42	43.6%

(second)	FORTRAN	C++ single core		C++ parallel	
pp	0.2640	0.5055	-91.5%	0.1980	25.0%
pA	3.5090	19.874	-466.4%	10.178	-190.1%
AA	397.96	482.28	-21.2%	224.42	43.6%

Ongoing activities and future plans

- Ongoing activities (HIJING++ v3.0)
  - code/compatibility tests & tuning
  - performance test
  - new physics (Shadowing, Quenching)
  - parallel version

- Future plans (HIJINGv3.x)
  - online access – documentation
  - AliRoot compatibility
  - multi thread and GPU support
  - GUI